Ultraviolet (UV)-Curable Coatings for Department of Defense (DoD) Applications

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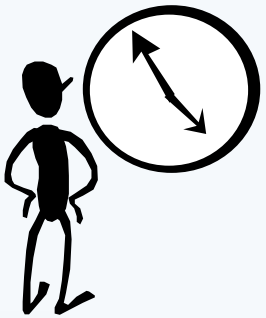
Overview

- Problem Statement
- Technology Review
- Air Force UV-Curable Coatings Program
  - Plans and Approach
  - Program Status and Results
    - Primers/One-Coats
    - Topcoats
      - Environmental Security Technology Certification Program (ESTCP)
    - Specialty Coatings Efforts
    - Lamp Technologies
    - The Future
- Summary
- Questions

Problem Statement

- Current USAF coatings require minimum 72 hour “dry to fly” time for polyurethane topcoat

Full Repaint Benefits (F-16 Example)			
Application	Current Dry Time	Using UV Cure	Time Saved
Primer	4 to 6 hours	30 minutes to 1 hour	3 to 5.5 hours
Topcoat	16 to 24 hours	30 minutes to 1 hour	15 to 23.5 hours
Stencils	72 hours	30 minutes to 1 hour	71 to 71.5 hours
Total possible savings per aircraft			89 to 100.5 hours



- Painting operations in depot and field work are a bottleneck in work flow
- Less time in maintenance = more availability in field
- Typical USAF coatings contain VOC of 340-420 g/L

Technology Maturity

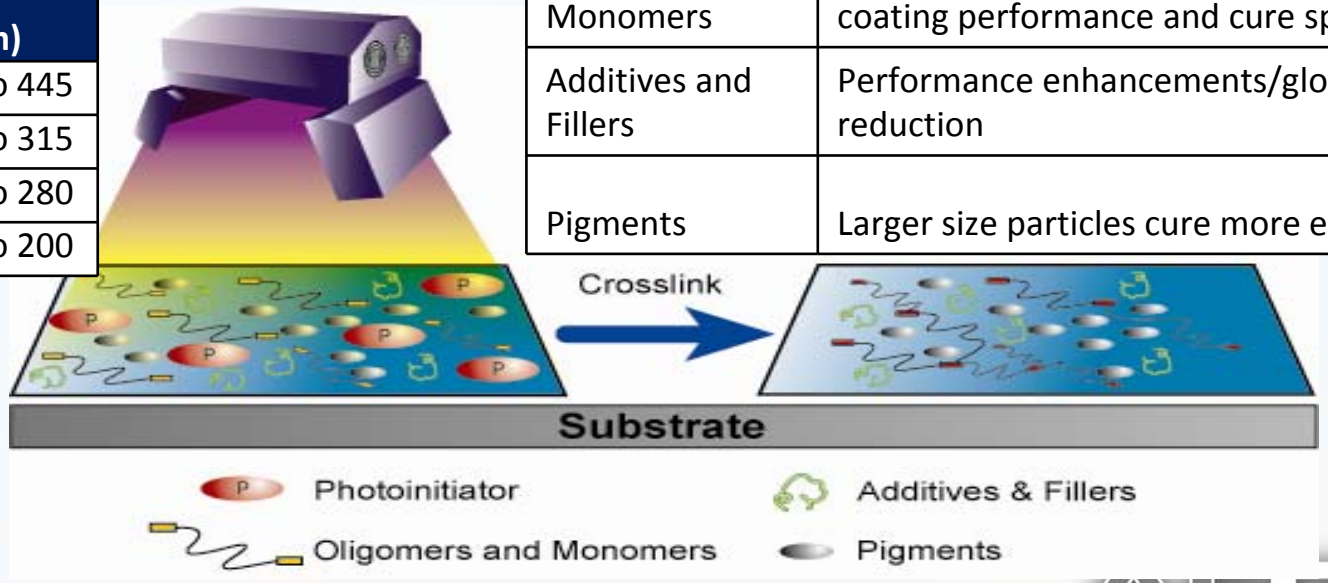
- Multi-billion dollar industry with over 25 year history
  - Wood finishing
  - Printing
  - CD coatings
  - Automotive refinishing
- Automotive refinishing environments are similar to aerospace maintenance environments
  - Commercially available automotive lamps can be adapted to aerospace maintenance applications

Technology Description

Benefits
No isocyanates, no HAPs, no VOCs
Cured in minutes
Apply by spray or brush
Single component, high solids

Wavelength in nanometers (nm)	
UVV	400 to 445
UVA	400 to 315
UVB	315 to 280
UVC	280 to 200

UV-curable Components	
Component	Description
Photoinitiators	Absorb specific frequencies of UV light and initiate polymerization
Oligomers	High molecular weight; control final cured film properties
Monomers	Diluents, adjust viscosity; contribute to coating performance and cure speed
Additives and Fillers	Performance enhancements/gloss reduction
Pigments	Larger size particles cure more easily



Air Force UV-Curable Program

UV-Curable Technology Team

Program Management
AFRL

Principal Stakeholders
Ogden Air Logistics Center (OO-ALC)
Oklahoma City Air Logistics Center (OC-ALC)
Warner Robins Air Logistics Center (WR-ALC)

Support Contractor
CTC Concurrent Technologies Corporation

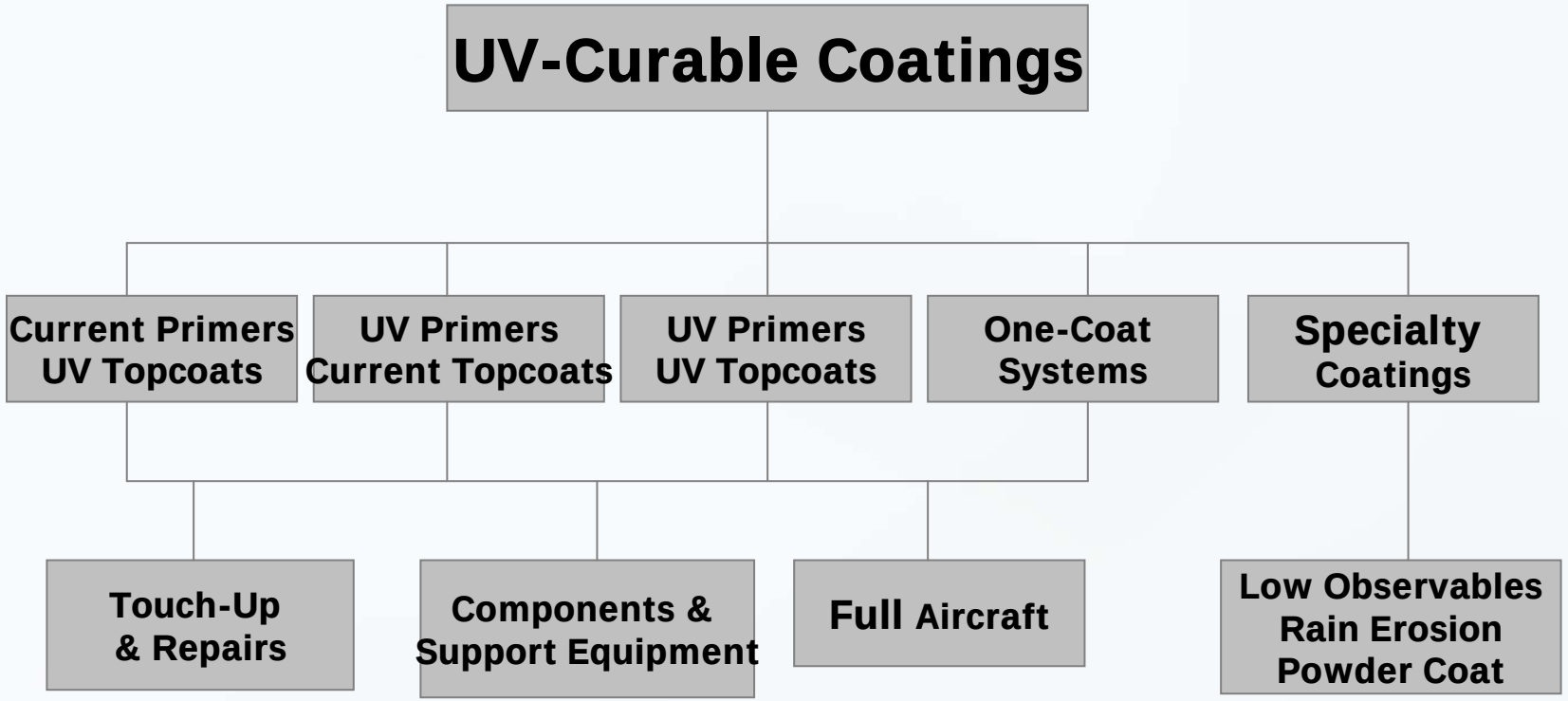
Project coordination
UV coating identification
DOD applications
System Integration
Testing, Evaluation & Documentation
Demonstration/Validation
Technology Transfer

Testing Facility
Coatings Technology Integration Office (CTIO)

Plans and Approach

- Leverage efforts
  - DoD/USAF R&D Investments
    - Small Business Innovative Research (SBIR)
    - Strategic Environmental Research and Development Program (SERDP)
    - Other
  - Industry and Education R&D
  - Commercial off-the-shelf technology
- Determine State of Industry
- Identify USAF Needs
- Transition UV-Curable Coating Technology

UV-Curable Coatings Strategy



Manual (simple geometries)

Automated (Full Aircraft)

Site Surveys

USAF Depots Surveyed

- Oklahoma City (OC-ALC), Ogden (OO-ALC), and Warner Robins (WR-ALC) Air Logistics Centers
- Potential field applications also identified

Results

- Phased Approach
  - Manual applications/simple geometries/on and off-aircraft applications
  - Further coating development/manual and automated applications
  - Full aircraft applications
- Initial targets
  - Topcoats
  - Stencil coatings and off-aircraft components
  - UVA curing frequency

COTS Evaluation

- Open RFI sent to commercial UV-curable coating vendors
- Minimal requirements
  - Opaque coating
  - Identify as topcoat, primer, one coat, or topcoat/primer system
  - Test panels applied and cured by vendor
- Coatings to be tested at CTIO
- Screening Test Protocol (2 phases)

COTS Screening Phase One

Primer	Topcoat	Code	Phase Two
UV-cure	Deft 99-GY-001(Color 36173)	A	Yes
UV-cure	Deft 99-GY-001(Color 36173)	B	Yes
UV-cure	Deft 99-GY-001(Color 36173)	C	Yes
UV-cure	Deft 99-GY-001(Color 36173)	D	Yes
UV-cure	Deft 99-GY-001(Color 36173)	E	Yes
UV-cure	Deft 99-GY-001(Color 36173)	F	Yes
UV-cure		G	Yes
UV-cure		I	No
UV-cure	Deft 99-GY-001(Color 36173)	J	Yes
Deft 02-Y-40	UV-cure	L	Yes
UV-cure		M	Yes
Deft 02-Y-40	UV-cure	N	Yes

Primer	Topcoat	Code	Phase Two
Deft 02-Y-40	UV-cure	O	No
UV-cure	Deft 99-GY-001(Color 36173)	P	Yes
UV-cure	Deft 99-GY-001(Color 36173)	Q	Yes
UV-cure	UV-cure	R	Yes
UV-cure		XA	Yes
Deft 02-Y-40	UV-cure	XB	No
UV-cure		XC	Yes
UV-cure		XD	Yes
Deft 02-Y-40	UV-cure	XE	No
Deft 02-Y-40	UV-cure	XF	No
Deft 02-Y-40	UV-cure	XG	Yes

COTS Phase One Tests

Tests	Primers (9 tested)	Topcoats (7 tested)	One-Coats and Systems (7 tested)	Target Criteria
Color	N/A	No Pass/Fail	No Pass/Fail	Opaque (no clear coats)
Gloss	N/A	No Pass/Fail	No Pass/Fail	Opaque (no clear coats)
Dry Film Thickness	No Pass/Fail	No Pass/Fail	No Pass/Fail	Per vendor; or 0.7-1.2 mils primer, 1.5-2.5 mils topcoat
Fluid Resistance				
Passed Pencil hardness	All pass	All pass	All pass	B or harder; baseline for fluid resist
Passed Fluid Resistance (lube oil)	N/A	L, N, O, XE, XF, XG	G, XC, XD,	Soften no more than 1 pencil hardness
Adhesion				
Passed Wet Tape	All pass	L, N, XG	G, M, R, XA, XC, XD	No peel; rate 4A or 5A
Passed Cross hatch	N/A	L, N, XE, XG	G, M, R, XC, XD	No peel; rate 4B or 5B
Flexibility				
Passed Low Temp	A, B, C, D, E, F, J, P	L, N, XB, XG	G, M, XC, XD	No cracking or adhesion loss
Passed GE Impact	B, D, E, J, Q	N	G, I	Minimum 5% elongation

Eighteen moved to Phase Two

COTS Phase Two Tests

Phase Two Testing		
Phase Two Tests	**Accelerated Weathering (Xenon Arc)**	**Salt Spray Resistance**
Coatings Tested	All Topcoats, Systems, and One-Coats	All Primers, Systems, and One-Coats
Pass/Fail Criteria	Delta E color change less than 1 after 500 hours; Gloss after 500 hours: *Type "gloss": Minimum 80* *Type "semi-gloss": Minimum 15* *Type "flat": Maximum 5*	No blistering, lifting, pitting, or corrosion after 2,000 hours of 5% salt spray

Coating Stack-up	Pass/Fail (w/ comments)	
	Accelerated Weathering	**Salt Spray**
Topcoat "L"	Pass Color Delta, gloss change >10	N/A
Topcoat "N"	Failed Color Delta, gloss change <5	N/A
System "M"	Failed Color Delta, gloss change <5	Pass
System "R"	Pass (best performer for weathering)	Fail
Topcoat "XG"	Pass Color Delta, gloss change <6	N/A
One-Coat "G"	Pass Color Delta, gloss change >10	Fail
One-Coat "XA"	Failed (panels pulled after 100 hours)	Pass (best performer)
One-Coat "XC"	Failed (color and gloss change >20)	Fail
One-Coat "XD"	Failed (color and gloss change >20)	Fail
Primer "A"	N/A	Fail
Primer "B"	N/A	Fail
Primer "C"	N/A	Fail
Primer "D"	N/A	Fail
Primer "E"	N/A	Fail
Primer "F"	N/A	Fail
Primer "J"	N/A	Pass
Primer "P"	N/A	Pass
Primer "Q"	N/A	Fail

Screening Test Conclusions

- COTS topcoats showed the most promise
  - Weather resistance and flexibility still key issues
- COTS primers and one-coats showed good corrosion protection potential
- All vendors provided results
- Round 2 Test Protocol Created
  - Apply/Cure at CTIO in UVA range
  - Protocol applies to topcoats, primers, one-coats, and systems
    - UV-cure topcoats began testing in Fall 2008
    - UV-cure primers, one-coats, and systems began testing in Spring 2009

Second Round
Primer, One-Coat, System Testing

Preliminary Results for Primers, One-coats, and UV-cure Systems

System	Primer	Topcoat	GE Impact	Low Temp Flex	Initial Hardness	Color Match	Gloss Match	MEK Rub	Initial Adhesion	Minimal Heat Resistance	Optimal Heat Resistance	30-Day Water
A	Deft 02-Y-40	Deft 03-GY-321	Fail	Pass	HB	Pass	Pass	Pass	Pass	Pass	Pass	Pass
B	Deft 02-Y-40	Deft 99-GY-001	Fail	Pass	HB	Pass	Pass	Pass	Pass	Pass	Pass	Pass
G	None	UV-curable coating	Fail	Fail	B	Fail	Fail	Pass	Fail	Pass	Fail	Fail
E	None	UV-curable coating	Fail	Fail	< 6B	Fail	Pass	Pass	Pass	Pass	Fail	Fail
I	None	UV-curable coating	Fail	Pass	2H	Fail	Pass	Pass	Pass	Pass	Fail	Fail
K	None	UV-curable coating	Fail	Pass	HB	Fail	Fail	Pass	Pass	Pass	Pass	Pass
D	UV-curable coating	UV-curable coating	Fail	Fail	F	Fail	Fail	Pass	Fail	Pass	Fail	Fail
C	UV-curable coating	UV-curable coating	Fail	Fail	< 6B	Fail	Pass	Pass	Pass	Pass	Fail	Fail
F	UV-curable coating	UV-curable coating	Fail	Pass	F	Fail	Pass	Pass	Pass	Pass	Fail	Pass
J	Deft 02-Y-40	UV-curable coating	Fail	Pass	HB	Fail	Fail	Pass	Pass	Pass	Fail	Pass
M	Deft 02-Y-40	UV-curable coating	Fail	Pass	HB	Fail	Fail	Pass	Fail	Pass	Fail	Pass
H	UV-curable coating	None	Pass	NR*	4H	NR*	NR*	Pass	Pass	NR*	NR*	Pass
L	UV-curable coating	None	Fail	NR*	F	NR*	NR*	Pass	Pass	NR*	NR*	Fail

*No requirement

Second Round
Primer, One-Coat, System Testing (cont.)

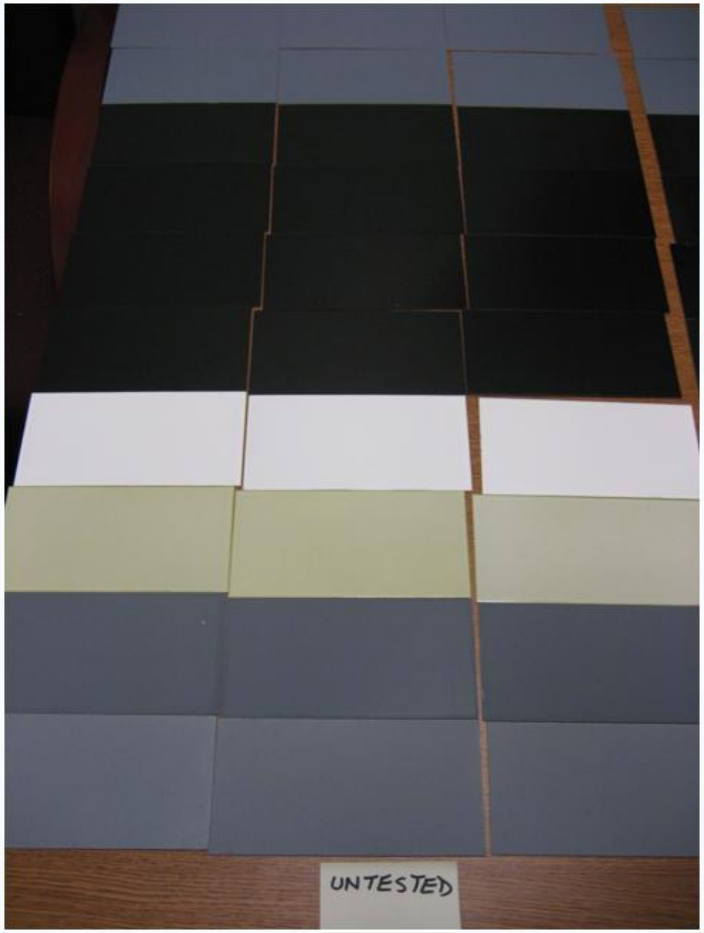
1000 Hour Filiform Corrosion

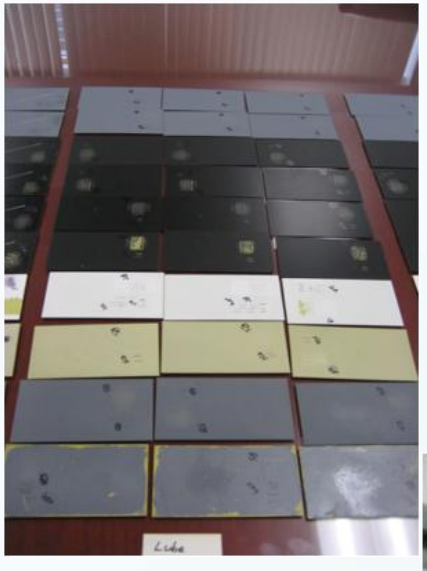
System	Primer	Topcoat	Filiform Growth Description	Result
A	Deft 02-Y-40	Deft 03-GY-321	All growth less than 1/8 inch	Pass
B	Deft 02-Y-40	Deft 99-GY-001	All growth less than 1/8 inch	Pass
C	UV-curable coating	UV-curable coating	All growth less than 1/8 inch	Pass
D	UV-curable coating	UV-curable coating	All growth less than 1/8 inch	Pass
F	UV-curable coating	UV-curable coating	All growth less than 1/8 inch	Pass
J	Deft 02-Y-40	UV-curable coating	All growth less than 1/8 inch	Pass
M	Deft 02-Y-40	UV-curable coating	All growth less than 1/8 inch	Pass
E	None	UV-curable coating	All growth less than 1/8 inch	Pass
G	None	UV-curable coating	The majority of the growth was over 1/4 inch	Fail
I	None	UV-curable coating	All growth less than 1/8 inch	Pass
K	None	UV-curable coating	All growth less than 1/8 inch	Pass
H	UV-curable coating	None	All growth less than 1/8 inch	Pass
L	UV-curable coating	None	The majority of growth was less than 1/8 inch, with a few between 1/8 and 1/4 inch	Pass

Second Round
Topcoat Testing

CODE	Color	Identifier
X	36173 Gray	Deft 03-GY-321 (Control corresponding to MIL-PRF-85285)
Y	36173 Gray	Deft 99-GY-001 (control corresponding to “Advanced performance Topcoat”)
A	Camo Black	Based on Screening “N”
B	Camo Black (1)	Based on Screening “N”
C	Camo Black (2)	Based on Screening “N”
D	Camo Black (3)	Based on Screening “N”
E	Gloss White	Based on Screening “G”
F	Gloss White	Based on Screening “O”
G	Camo Gray	Based on Screening “O”
H	Camo Gray	Based on Screening “G”

Second Round
Topcoat Test Panels





Second Round
Topcoat Test Results

Coating System	Color	Color Match	Gloss Match	Wet Tape	Cross Hatch	Low Temp Flex	GE Impact	Pencil Hardness	Weathering (500-hrs)			
									Color Change	Gloss Change	Post Test Low Temp Flexibility	Post Test GE Impact
X (CONTROL)	Camo Gray 36173	Pass	Pass	Pass	Pass	Pass	Fail	HB	Pass	Pass	Pass	N/A
Y (CONTROL)	Camo Gray 36173	Pass	Pass	Pass	Pass	Pass	Fail	HB	Pass	Pass	Pass	N/A
A	Camo Black 37038	Fail	Fail	Pass	Pass	Pass	Fail	F	Pass	N/A	Pass	N/A
B	Camo Black 37038	Fail	Fail	Pass	Fail	Pass	Fail	HB	Pass	N/A	Pass	N/A
C	Camo Black 37038	Fail	Fail	Pass	Pass	Pass	Fail	HB	Pass	N/A	Pass	N/A
D	Camo Black 37038	Fail	Fail	Pass	Fail	Pass	Fail	HB	Fail	N/A	Pass	N/A
E	Gloss White 17925	Fail	Fail	Fail	Fail	Pass	Fail	B	Pass	N/A	Fail	N/A
F	Gloss White 17925	Fail	Fail	Pass	Fail	Pass	Fail	HB	Fail	N/A	Fail	N/A
G	Camo Gray 36173	Fail	Pass	Pass	Pass	Pass	Fail	2B	Pass	Fail	Pass	N/A
H	Camo Gray 36173	Fail	Pass	Pass	Pass	Pass	Fail	< 6B	Pass	N/A	Pass	N/A

Second Round
Topcoat Results (cont.)

Coating System	Color	Cleanability	Heat Resistance (1-hr 250 F)	Opacity	Lube Oil Resistance	Hydraulic Fluid Resistance (24-hr)	Jet Fuel Resistance (7-day)
X (CONTROL)	Camo Gray 36173	Fail	Pass	Pass	Pass	Pass	Pass
Y (CONTROL)	Camo Gray 36173	Fail	Pass	Pass	Pass	Pass	Pass
A	Camo Black 37038	Not required	Pass	Pass	Pass	Pass	Pass
B	Camo Black 37038	Not required	Pass	Pass	Pass	Pass	Pass
C	Camo Black 37038	Not required	Pass	Pass	Pass	Pass	Pass
D	Camo Black 37038	Not required	Pass	Pass	Pass	Pass	Pass
E	Gloss White 17925	Pass	Pass	Pass	Fail	Pass	Pass
F	Gloss White 17925	Pass	Fail	Fail	Pass	Pass	Pass
G	Camo Gray 36173	Fail	Pass	Pass	Pass	Pass	Pass
H	Camo Gray 36173	Pass	Pass	Pass	Pass	Pass	Pass

Second Round
Topcoat Conclusions

- Coatings A, F, and G closest to DoD aerospace requirements for their colors
  - Proceed to optimize topcoats under follow-on Topcoat Project

Color	FED-STD-595C Color Number	Applications
Camo Black	37038	Used in many stencil applications across platforms and services (including C-130)
Camo Gray	36118	F-16 markings
Camo Gray	36173	C-130 escape hatch, life raft cover
Gloss White	17860	Coast Guard White HH-60, HH-25
Gloss White	17925	White used for Air Force and Navy (P-3 stencils, F-16 wheels)

UV-Curable Topcoat Project

- Environmental Security Technology Certification Program (ESTCP) Project “UV-Curable Coatings for Aerospace Applications”
  - Demonstrate and evaluate UV-curable topcoats
  - Verify through laboratory and field testing that UV-curable topcoats can
    - Meet aerospace performance requirements
    - Reduce environmental burden
    - Reduce costs
    - Increase production throughput
- Joint Service Effort
  - Air Force: Ogden Air Logistics Center (OO-ALC)
  - Navy: Fleet Readiness Center Southeast (FRCSE)
  - Coast Guard: United States Coast Guard Aviation Logistics Center (USCG ALC)

Topcoat Project Organization

ESTCP Principal Investigator
Glenn Baker

Program Management
Tom Naguy
Randy Straw

CTC
Georgette Nelson, *CTC* Project Manager
Matthew Campbell, Technical Support
Steve Finley, Technical Support

CTC Concurrent Technologies Corporation

CTIO Lab Testing
Corey Bliss

Principal Stakeholders
OO-ALC
OC-ALC
WR-ALC
FRCSE
USCG ALC

NAVAIR

Coating Suppliers

AFRL

Topcoat Technical Approach

Project Approach

Task III – Technology Transition

- Modify specifications and process documents
- Transition equipment to OO-ALC and train staff
- Compare performance versus baseline data
- Prepare Final Reports & Briefing

Task II – Demonstration/Validation

- Make final selection of coatings for dem/val (*in-progress*)
- Conduct lab testing and optimization (*in-progress*)
- Conduct field testing

Task I – Planning for Demonstration/Validation

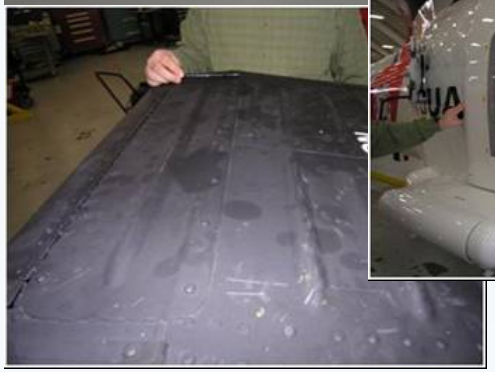
- Draft Project Management Plan (PMP) (*complete*)
- Conduct Initial Cost-Benefit Analysis (ICBA) and Performance Baseline (*complete*)
- Draft Joint Test Protocol (JTP) (*complete*)
- Draft Demonstration Plan (*complete*)

Topcoat Targeted Applications

- OO-ALC

C-130
- •Stenciling
- •Escape hatches
- •Life raft covers
- •Prop tips

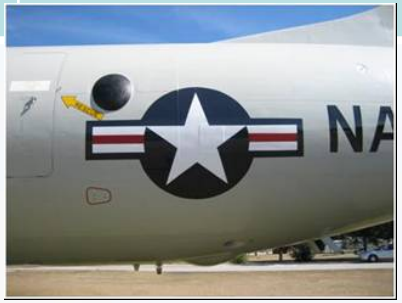
F-16
- •Stenciling
- •Wheels



- USCG ALC

HH-60
- •Crew entry door
- •External fuel tanks
- •Fuel tank pylons

HU-25
- •Panel covers
- •Stenciling



- FRCSE

P-3
- •Stenciling
- •Wheels

Joint Test Protocol

Appearance	
Color	ΔE of less than 1 from standard
Gloss	At 60°: ≥90 for gloss; ≤5 for flat;
Adhesion	
Wet Tape	No peel away; target rating of 4A or 5A
Cross Hatch	No peel away; target rating of 4B or 5B
Flexibility	
Low Temperature	No cracking or adhesion loss over 1 inch bend (gloss and semi-gloss) or 2 inch bend (flat)
GE Impact	Minimum of 40% elongation; no cracking, crazing, or loss of adhesion
Resistance	
Pencil Hardness	2B or harder; initial hardness - data point for fluid resistance
Fluid Resistance	Softening no more than two (2) pencil hardness unit; no blistering or defects after exposure to lube oil, hydraulic fluid and JP-8 fuel

Resistance	
Accelerated Weathering (Color and Gloss)	Color change (ΔE) of less than 1 after 200 hours; Min gloss of 90 for gloss; max five (5) for flat
Heat Resistance	Color change (ΔE) of less than 1 after exposure to 250 ± 5ºF for 60 minutes
Humidity Resistance	No blistering, softening, loss of adhesion or defects
Cleanability	Cleaning Efficiency ≥ 75%
Repairability	
Scuff sand /Wet Tape	No peel away; target rating of 4A or 5A
Scuff sand /Cross Hatch	No peel away; target rating of 4B or 5B
Strippability	
Chemical Strippers	Removal of the coating to the substrate
Dry Media (blasting)	Removal of the coating to the substrate

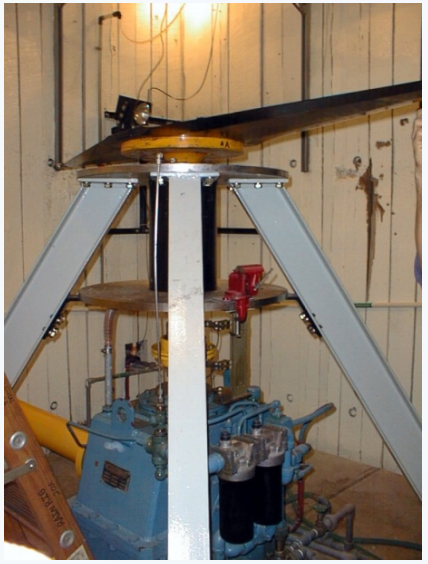
Based on MIL-PRF-85285 / MIL-PRF-32239 and input from subject matter experts

Future Plans

- Demonstration Plan to be approved by stakeholders and ESTCP
- Selected vendors to conduct final reformulation and submit for testing to JTP at the CTIO
- Purchase portable lamp system for use during demonstration
- Conduct demonstrations at stakeholder sites
  - Collect additional cost and performance data to verify savings
  - Monitor field performance of UV-curable coatings for a year
- Transfer technology to primary stakeholder at OO-ALC

Specialty UV-Cure Coatings

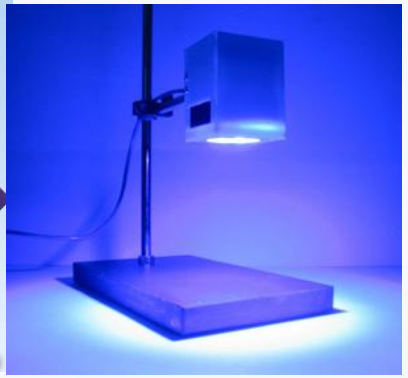
- Rain Erosion Coatings
  - o Current coating high VOCs/HAPs
  - o Production burden
    - ✓ 12 hours apply; 5 to 7 days cure
    - ✓ Fluctuates with temperature and humidity
    - ✓ Cause bottlenecks in production
    - ✓ Often results in rework
  - o One commercial source
  - o Suggested minimum performance
    - ✓ 2000-3000 PSI tensile strength
    - ✓ 300%-500% elongation
  - o Four potential UV-curable rain erosion suppliers identified
  - o On-going



UV-Cure Lamp Technology

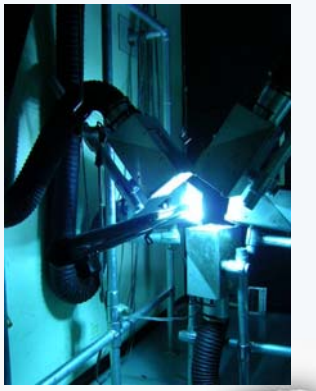
Three broad types of lamp technology

- Arc (electrode) lamp
  - Mature technology, wide use
  - Arc across electrodes excites mercury vapor
  - Simple, cost-effective
  - Electrode degradation and short bulb life are concerns



- Microwave (electrodeless) lamp
  - Microwave radiation excites mercury
  - Offers more reliable, longer lasting bulbs at higher cost

- LED Lamp
  - A semiconductor diode emits light
  - Manufactured to emit a specific, narrow optical spectrum
  - Very long life (50,000 – 100,000 hrs)
  - Instant on/off control and efficient energy conversion
  - High equipment costs, particularly for panels required for large area curing



UV Lamp systems work well with automation

The Future

- Depot and field level transition of UV-curable topcoats
- Primers, One-coats, and Systems
  - Preliminary data indicates corrosion protection
  - Reformulation and continued test and evaluation
  - Depot and field level transition
- Robotics
  - Full spectrum light manipulated by robot in enclosed chamber
  - Small robotic systems for specialty applications such as rain erosion coatings on radomes
  - Full aircraft paint and cure with the same robot
- Lamp technology development for aerospace applications

Summary

- DoD has dedicated significant funds and time to develop UV-curable coatings and transition to end users
- UV-curable coatings will significantly impact DoD maintenance processes
  - "Dry to fly" time reduction
  - Environmental benefits
  - Reduced man hours per painting event
- Multi-step technology transition program leading up to full scale aircraft painting

Maintenance Benefits		
Process	Current Practice	Using UV Cure
F-16 Maintenance	4 days repair paint and stencil	2 days repair paint and stencil
Off aircraft parts and support equipment	Paint, wait for part to dry 24 to 36 hours	Paint, put part into service or reassembly

Contact Info

Environmental and Energy Quality Team	
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